Density Based Screening of Additively Manufactured Parts

SAMUEL CORDNER

TRACIE PRATER

NASA MARSHALL SPACE FLIGHT CENTER

JUDITH SCHNEIDER

UNIVERSITY OF ALABAMA IN HUNTSVILLE

Objectives

1. What effect does the heat treatment, including HIP, have on pore size, area fraction, and morphology?
2. How effective are density measurements in evaluating porosity in IN718?
3. Can density be used as initial screening acceptance of Additively Manufactured Parts?

Selected laser melting (SLM)

M1 Concept Laser Selected Laser Melting (SLM) equipped with an IPG 400W 1064nm fiber laser

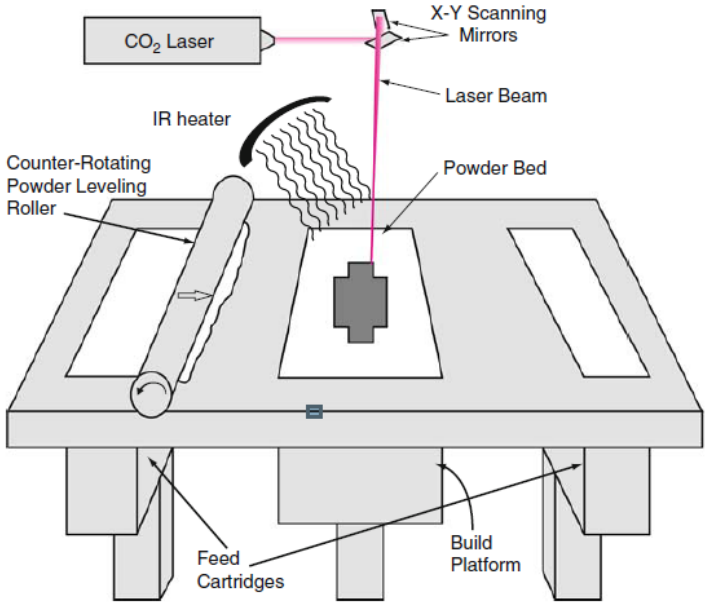


Illustration of a powder bed based, SLM process

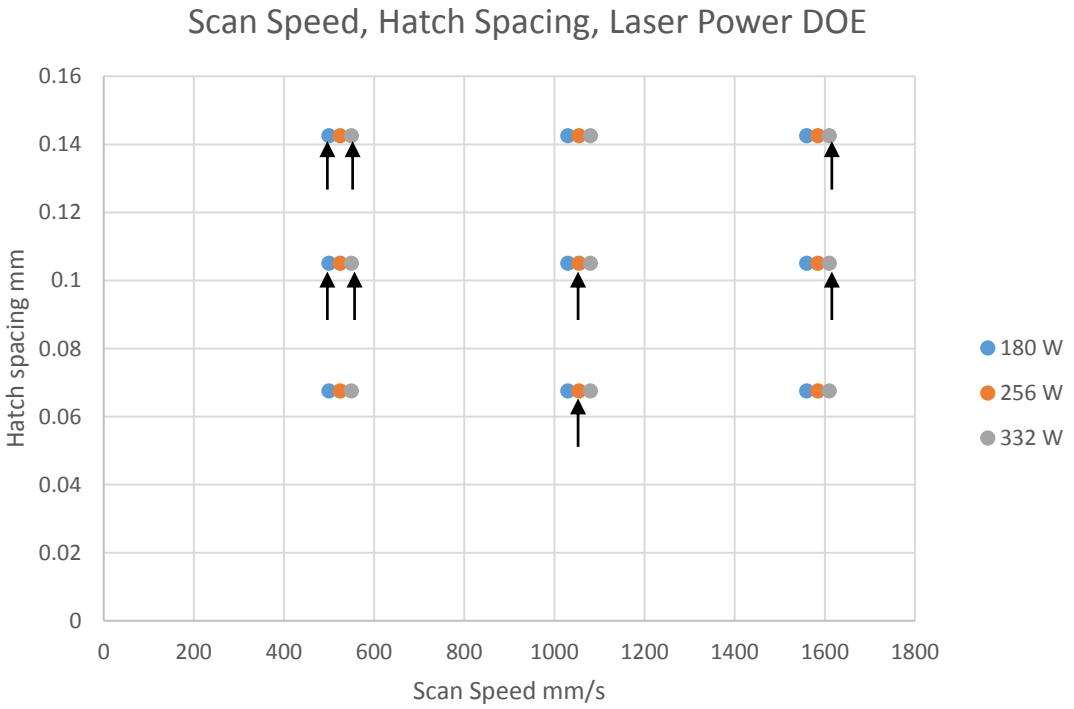
R. S. Gibson, *Additive Manufacturing Technologies*, New York: Springer Science+Business Media, LLC, 2010.

Density Measurements

- Density is a bulk determination of the mass of an objective divided by its volume.
- In simple shapes, the volume can be measured directly.
- In complex shapes, the volume is often determined using Archimedes principle.
- Both methods are compared along with metallographic sectioning to determine sensitivity of the approaches.
- Can density provide a process for rapid screening to determine the quality of an AM part?

Test Matrix

- Full Test Matrix 108 samples
  - Vary Scan Speed, Hatch Spacing, Laser Power, Heat Treatment, Laser Disposition
- Arrows mark further study
  - Chosen based on high and low density of 108 samples and organizational interest



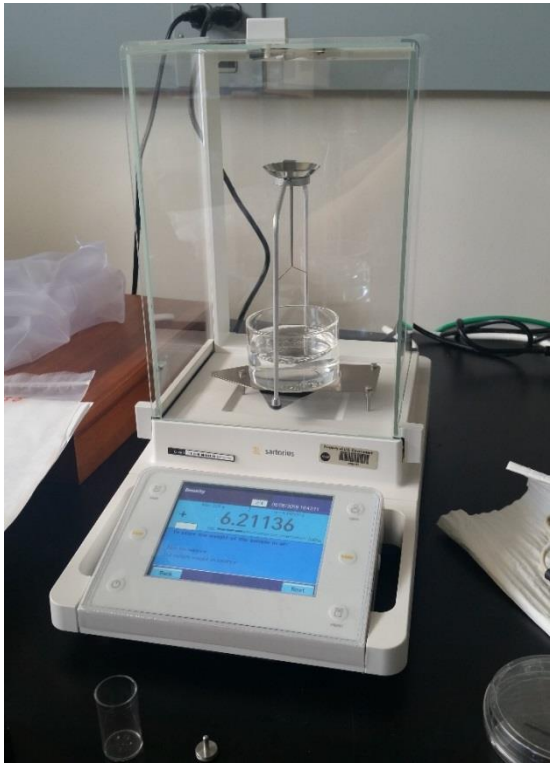
Two print patterns were used for each set of parameters with constant layer thickness of 45 µm.

ID was removed prior to measurements.

Archimedes Density Standards

Two ASTM standards were evaluated:

- ASTM C830 - Developed for criteria for selection and use of refractory products.
  - Dry weight recorded after heating specimens to 220 to 230°F.
  - Specimens placed under vacuum prior to introducing isopropyl alcohol
  - Submersed specimens held under pressure for 60 minutes before saturated weight recorded.
- ASTM B311 - Developed for PM parts with < 2% porosity.
  - Weigh dry mass
  - Weigh submerged mass
  - No additional preparation



Evaluations of porosity

- Apparent Porosity (ASTM C830):

$$P = \frac{W-D}{W-S} * \rho$$

- Bulk Density (ASTM C830) (ASTM B311):

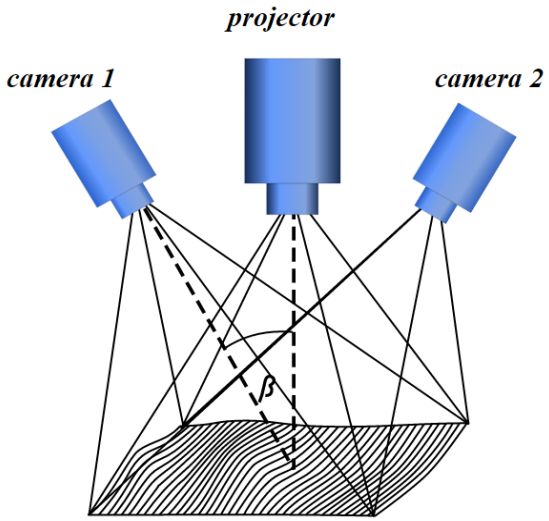
$$B = \frac{D}{W-S} * \rho \qquad D = \frac{A}{A-S} * \rho$$

- Apparent Specific Gravity (ASTM C830) :

$$T = \frac{D}{D-S} * \frac{\rho}{\rho_w}$$

Volume measurements

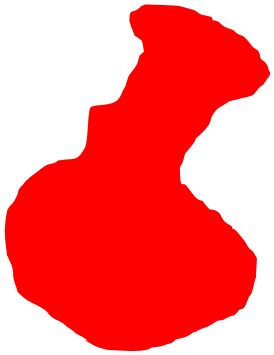
Structured Light Scanning utilized a ATOS III Triple Scan GOM - 3D scanner



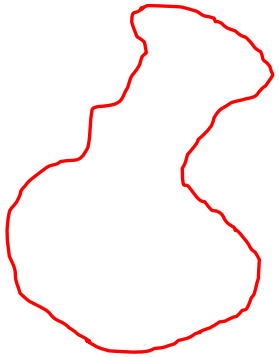
Volume obtained using structured light scanning was compared with traditional length measurements

http://www.aniwaa.com/product/3d-scanners/gom-atos-iii-triple-scan/. [Accessed 13 07 2016].

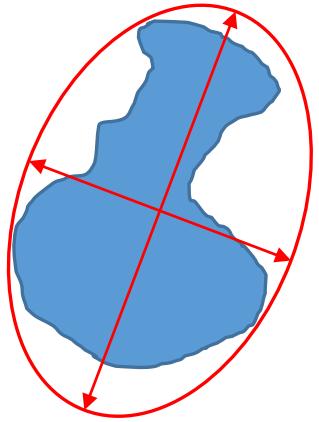
Common pore size measurements



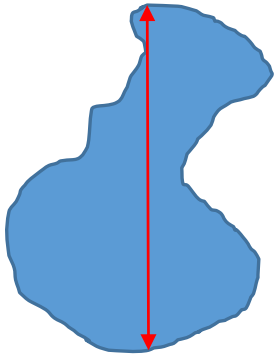
Area



Perimeter



Bounding Ellipse
Major and Minor



Feret

Common pore morphology measurements

- Roundness: Minor axis / Major axis
- Circularity: $4\pi \times Area / Perimeter^2$

R: 1.00
C: 1.00

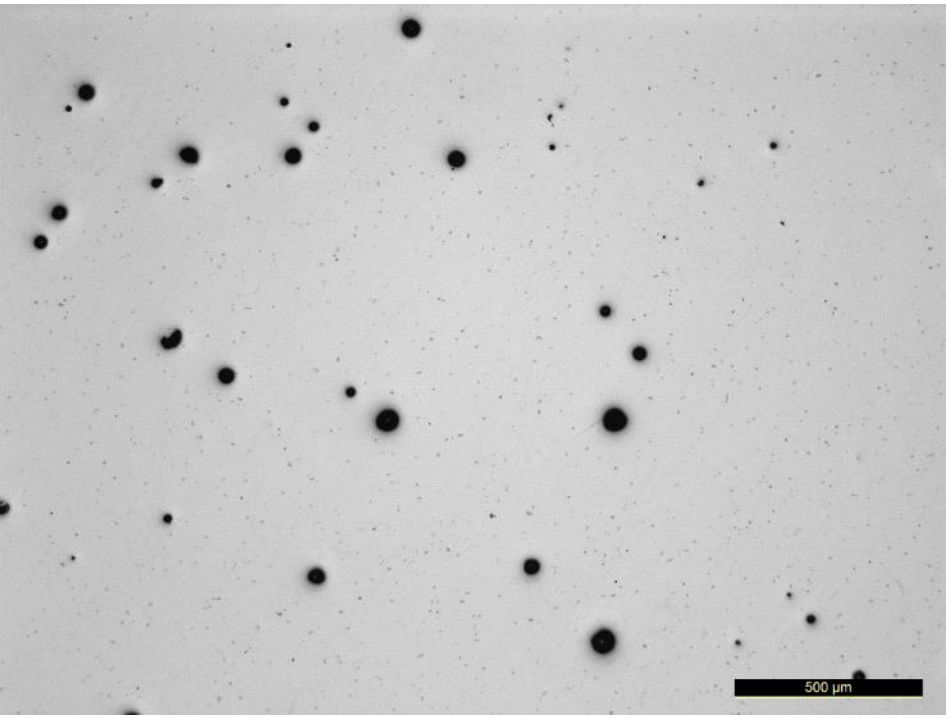
R: 0.22
C: 0.69

R: 0.33
C: 0.77

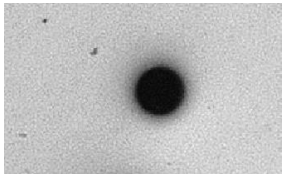
R: 1.00
C: 0.42

R: 0.92
C: 0.79

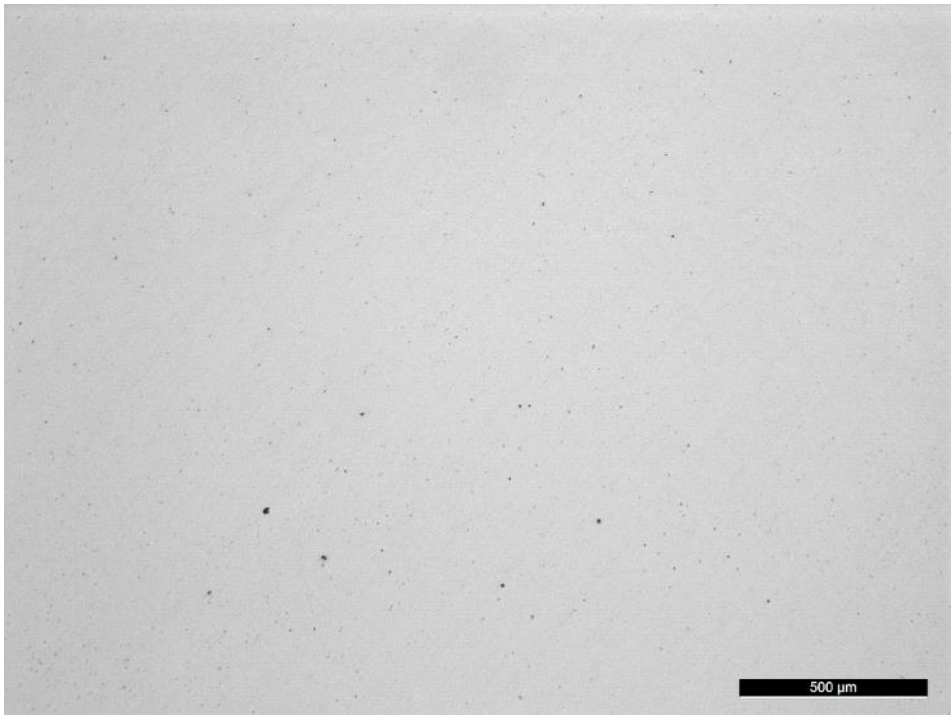
HIP reduced size, morphology, and area fraction of pores



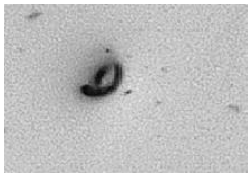
Before Heat Treatment



High Roundness
High Circularity

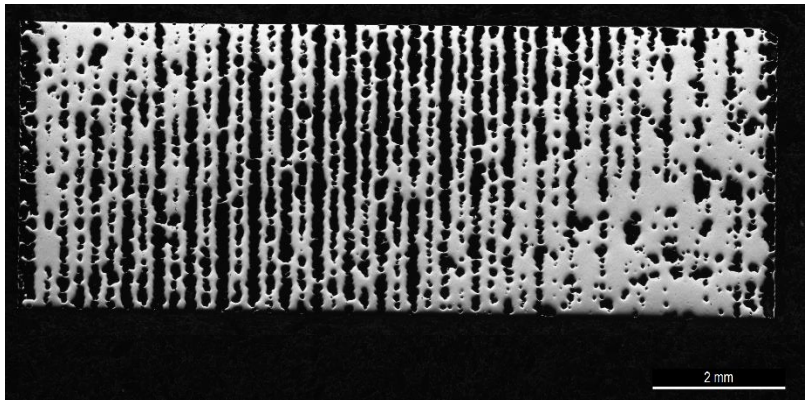


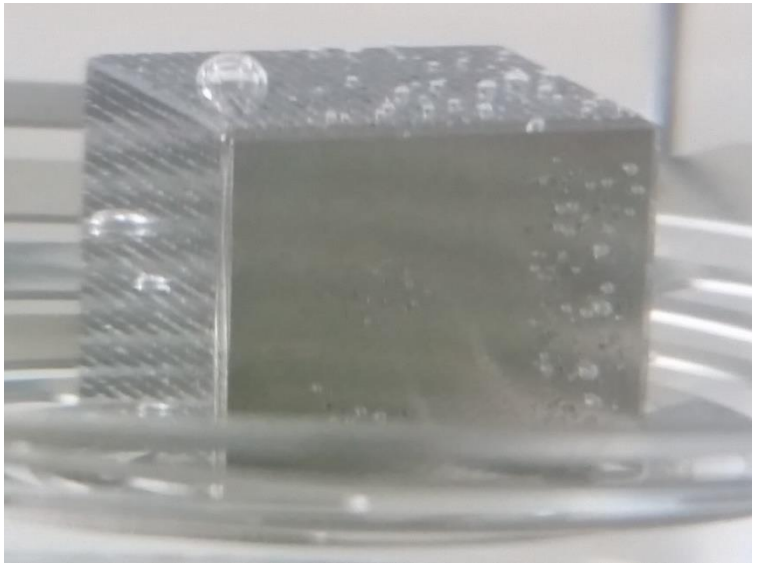
After Heat Treatment



High Roundness
Low Circularity

Challenges with Archimedes density measurements



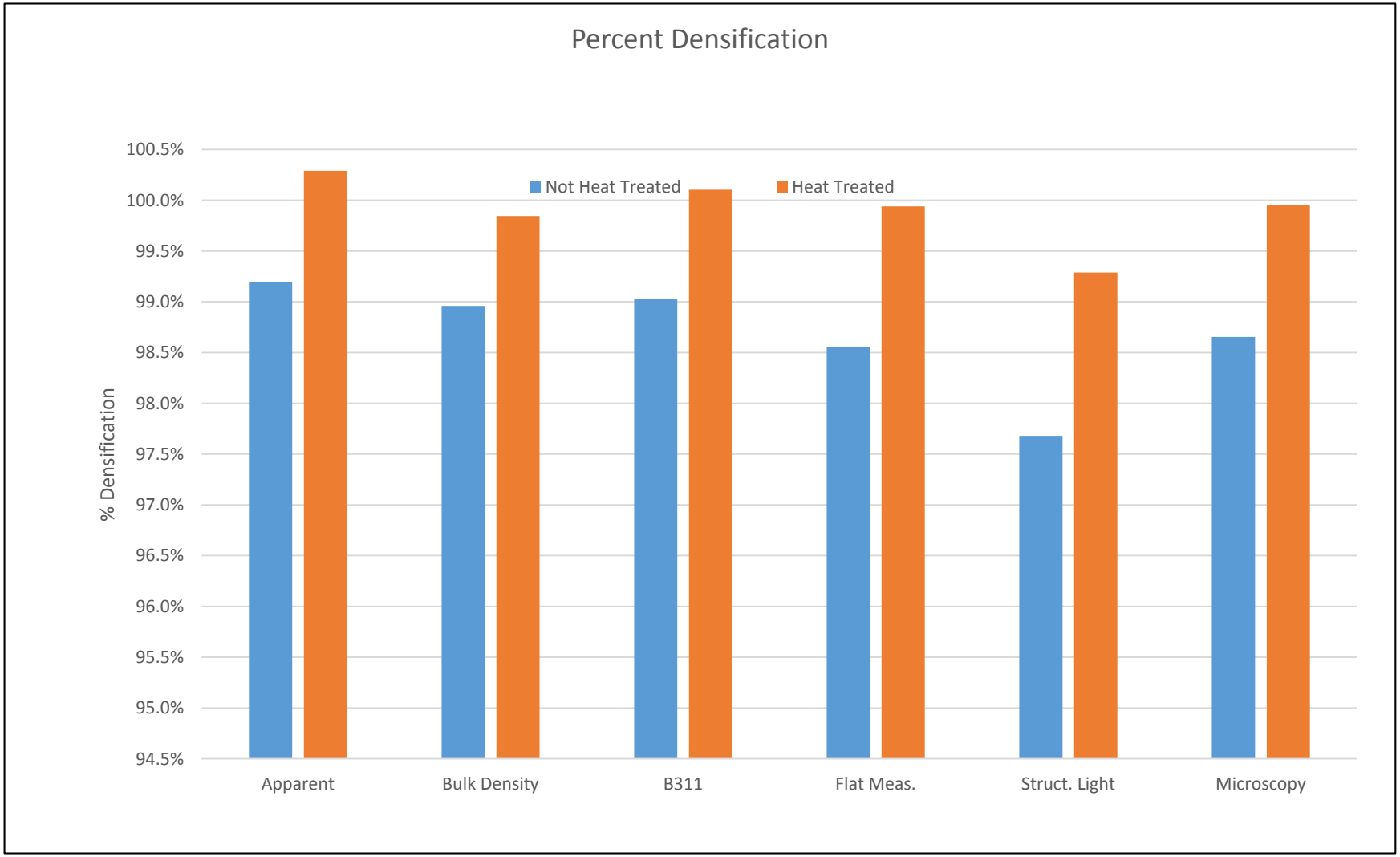


Trapped air bubbles invalidate measurements.

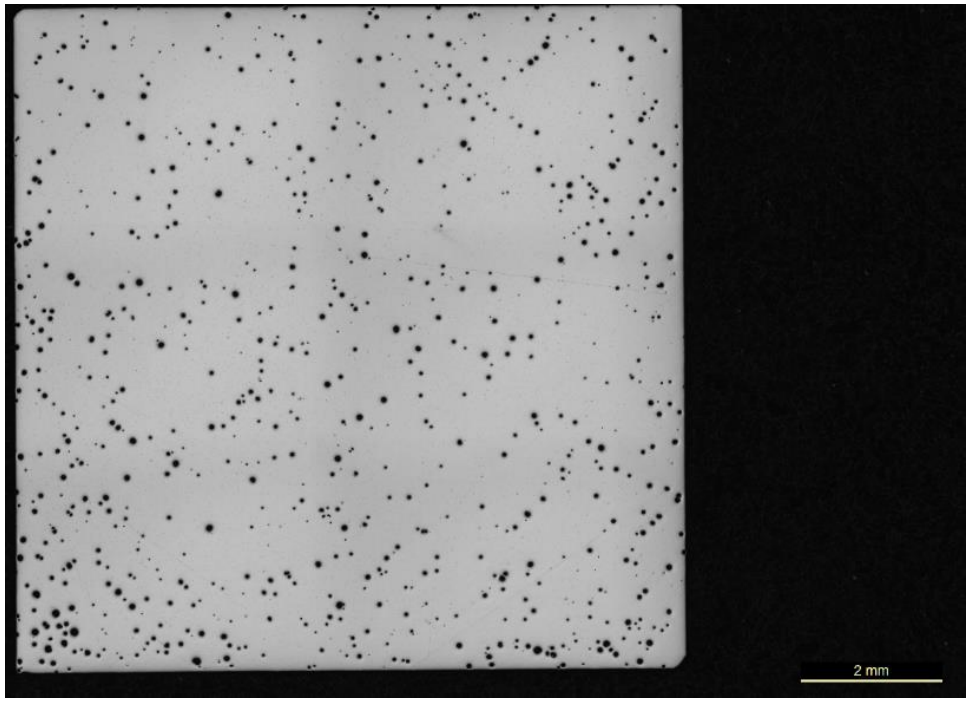
Inability to seal if porosity is interconnected.

Density: 7.2 g/cm^3

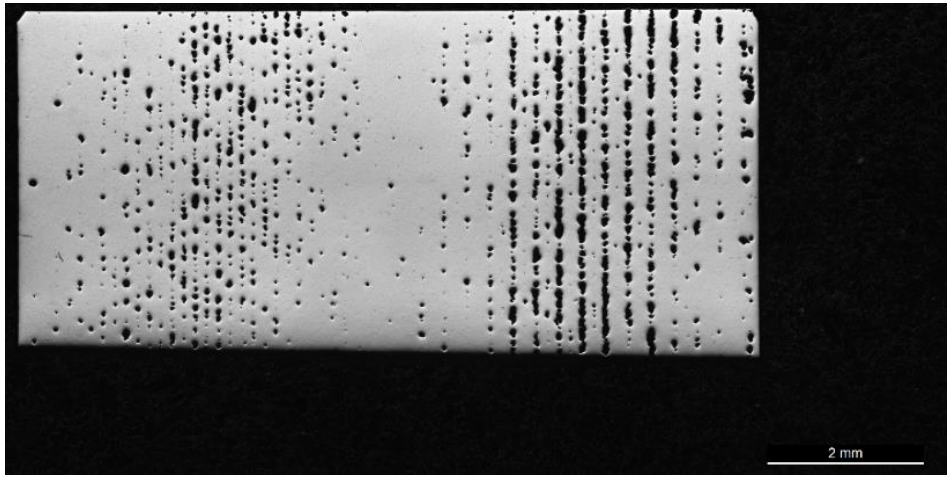
Similar density observed with all techniques



Porosity gradients observed



Layer Orientation
(XY)



Build Direction
(Z)

Density measurements do not give an indication of how pores are distributed

Summary

1. Can a relationship be established between processing parameters and the resulting porosity of an additively manufactured part?
   - no trends observed between process parameters and density within subset evaluated.
2. What effect does the heat treatment, including HIP, have on pore size, area fraction, and morphology?
   - The pore size, area, and morphology are reduced following heat treatment. Pore morphology only revealed by metallographic analysis.
3. How effective are density measurements in evaluating porosity in IN718?
   - Archimedes density can provide a rapid screening of a part for acceptable porosity levels.
4. Can density be used as initial screening acceptance of Additively Manufactured Parts?
   - Density is directly relatable to porosity. To assure that no large amounts of porosity are in a part, density can be used. Density will not give morphology of pores.

Acknowledgements

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